The ROSAT Deep Cluster Survey: Constraints on Cosmology

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Abstract. We use the ROSAT Deep Cluster Survey (RDCS) with the purpose of tracing the evolution of the cluster abundance out to $z \simeq 0.8$ and constrain cosmological models. We resort to a phenomenological prescription to convert masses into X–ray fluxes and apply a maximum–likelihood approach to the RDCS redshift– and luminosity–distribution. As a main result we find that, even changing the shape and the evolution on the L_{bol}–T_X relation within the observational uncertainties, a critical density Universe is always excluded at more than 3σ level. By assuming a non–evolving X–ray luminosity–temperature relation with shape $L_{bol} \propto T_X^3$, it is $\Omega_m = 0.35^{+0.35}_{-0.25}$ and $\sigma_8 = 0.76^{+0.38}_{-0.14}$ ($\Omega_m = 0.42^{+0.35}_{-0.27}$ and $\sigma_8 = 0.68^{+0.21}_{-0.12}$) for flat (open) models, while no significant constraints are found for the power–spectrum shape parameter Γ. Uncertainties are 3σ confidence levels for three significant fitting parameters.

1 Introduction

The mass function of local ($z \lesssim 0.1$) galaxy clusters has been used as a stringent constraint for cosmological models. Independent analyses have shown that $\sigma_8 \Omega_m^{\gamma(\Omega_m)} \simeq 0.5$–$0.6$, where Ω_m is the density parameter, σ_8 the r.m.s. fluctuation amplitude within a sphere of $8\,h^{-1}$Mpc ($h = H_0/100\,\mathrm{km\,s^{-1}\ Mpc^{-1}}$) radius and $\gamma(\Omega_m) \simeq 0.4 - 0.6$ [6, 7]. The increasing availability of X–ray temperatures for distant ($z \gtrsim 0.3$) clusters is providing a handle to estimate the density parameter which best reproduces the evolution of the cluster abundance [6, 5, 2] (see also Henry, this volume, for a review), A limitation of this approach comes from the small size of the current samples [14].

An alternative way to trace the evolution of the cluster abundance is to rely on the luminosity and redshift distribution of X-ray flux–limited cluster samples

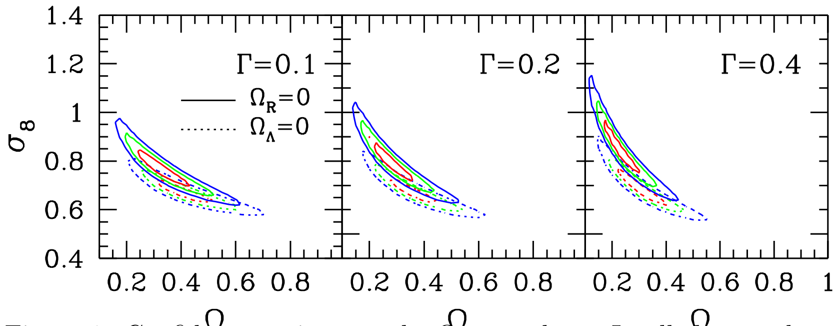

Figure 1: Confidence regions on the Ω_m–σ_8 plane. In all the panels, solid contours and dashed contours are for flat and open models, respectively. Here $\alpha = 3.5$, $A = 0$ and $\beta = 1.15$ are assumed for the mass–luminosity conversion. Contours are 1σ, 2σ and 3σ c.l. for two significant parameters.

[13, 3, 10]. The advantage of this approach lies in the availability of large samples, with well understood selection functions. As a limitation, however, one has to face with the uncertain relation between cluster masses and X–ray luminosities. The ROSAT Deep Cluster Survey (RDCS) [12] provides a flux–limited complete sample of clusters identified in the *ROSAT* PSPC archive and including $\gtrsim 100$ spectroscopically confirmed systems. In the following we will outline the main results of a comparison between the RDCS sample and the predictions of cosmological models. The analysis of RDCS for constraining the evolution of the X–ray luminosity function is contained in a separate paper (Rosati et al., this volume).

2 X–ray cluster bias: from luminosity to mass

The Press-Schechter approach is used in our analysis, as it provides an accurate mass function in the range of masses probed by the RDCS [3]. The conversion from masses to X-ray luminosities, which is required in analysis of any flux-limited sample is implemented as follows: **(a)** convert mass into temperature by assuming virialization, hydrostatic equilibrium and isothermal gas distribution; **(b)** convert temperature into bolometric luminosity according to $L_{bol} \propto T^\alpha (1+z)^A$; **(c)** compute the bolometric correction to the 0.5-2.0 keV band.

The critical step is represented by the choice for the L_{bol}–T_X relation. Low redshift data for $T \gtrsim 3\,$keV indicates that $\alpha \simeq 2.7$–3.5, depending on the sample and the data analysis technique [15], with a reduction of the scatter after account for the effect of cooling flows in central cluster regions [1]. At lower temperatures, evidence has been found for a steepening of the L_{bol}–T_X relation below 1 keV

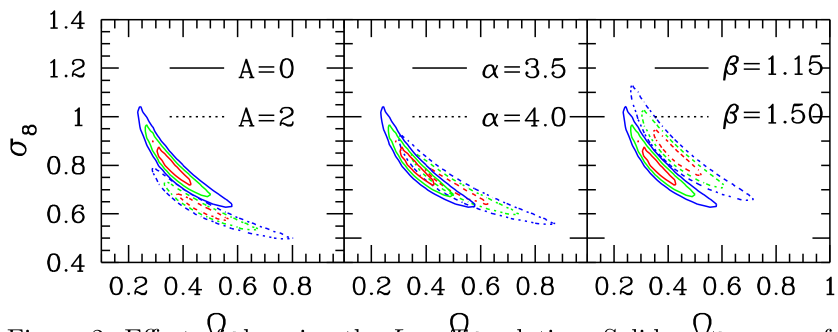

Figure 2: Effect of changing the L_{bol}–T_X relation. Solid contours are from assuming $\Gamma = 0.2$, $\alpha = 3.5$, $A = 0$ and $\beta = 1.15$. Contours have the same meaning as in Fig. 1.

[9]. As for the evolution of the L_{bol}–T_X relation, existent data out to $z \simeq 0.4$ [8] and, possibly, out to $z \sim 0.8$ [4] are consistent with no evolution (i.e., $A \simeq 0$). Instead of assuming a unique mass–luminosity conversion, in the following we will show how final constraints on cosmological parameters changes as the L_{bol}–T_X and M–T_X relations are varied.

3 Analysis and results

The RDCS subsample, that we will use in the following analysis, has a flux–limit of $S_{lim} = 3.5 \times 10^{-14}\,\mathrm{erg\,s^{-1}cm^{-2}}$ and contains 81 clusters with measured redshifts out to $z = 0.85$ over a 33 sq. deg. area [11]. In order to fully exploit the information provided by the RDCS, we resort to a maximum–likelihood approach, in which model predictions are compared to the RDCS cluster distribution on the (L, z) plane. To this purpose, let $\phi(L, z)$ be the Press–Schechter based luminosity function, as predicted by a given model, so that $\phi(L, z)\,(dV/dz)\; dz\,dL$ is the expected number density of clusters in the comoving volume element $(dV/dz)\,dz$ and in the luminosity interval dL. Therefore, the expected number of clusters in RDCS lying in the $dz\,dL$ element of the (L, z) plane is $\lambda(z, L)dzdL = \rho(z, L)$ $f_{sky}[S(z, L)](dV/dz)dzdL$. Here f_{sky} is the flux–dependent RDCS sky–coverage.

The likelihood function $\mathcal{L}$ is defined as the product of the probabilities of observing exactly one cluster in $dz\,dL$ at each of the (z_i, L_i) positions occupied by the RDCS clusters, and of the probabilities of observing zero clusters in all the other differential elements of the (z, L) plane which are accessible to RDCS. Assuming Poisson statistics for such probabilities and defining $S = -2\ln\mathcal{L}$, it is $S = -2\sum_{i=1}^{N_{occ}} \ln[\rho(z_i, L_i)] + 2\int dz \int dL\, \lambda(z, L)$, where the sum runs over the occupied elements of the (z, L) plane. Model predictions are also convolved with statistical errors on measured fluxes, as well as with uncertainties in the luminosity–mass relation associated to a $\simeq 30\%$ scatter in the L_{bol}–T_X relation and to a 20% uncertainty in the mass–temperature conversion. Best estimates of the model parameters are obtained by minimizing S.

In Figure 1 we show the resulting constraints on the σ_8–Ω_m plane for different values of the shape parameter Γ, based on assuming $\alpha = 3.5$ and $A = 0$ for the L_{bol}–T_X relation. It is clear that low–density models are always preferred, quite independent of Γ. We find $\Omega_m = 0.35^{+0.35}_{-0.25}$ and $\sigma_8 = 0.76^{+0.38}_{-0.14}$ ($\Omega_m = 0.42^{+0.35}_{-0.27}$ and $\sigma_8 = 0.68^{+0.21}_{-0.12}$) for flat (open) models, where uncertainties correspond to 3σ confidence level for three significant fitting parameter. No significant constraints are instead found for Γ. In order to verify under which circumstances a critical density model may still be viable, we show in Figure 2 the effect of changing the parameters of the L_{bol}–T_X relation. Although best–fitting values of Ω_m and σ_8 move somewhat on the parameter space, neither a rather strong evolution nor a quite steep profile for the L_{bol}–T_X relation can accommodate a critical density Universe: an $\Omega_m = 1$ Universe is always a $> 3\sigma$ event, even allowing for values of the A and α parameters which are strongly disfavored by present data.

Based on these results, we point out that deep flux–limited X–ray cluster samples, like RDCS, which cover a large redshift baseline ($0.1 \lesssim z \lesssim 1.2$) and include a fairly large number of clusters ($\gtrsim 100$) do indeed place significant constraints on cosmological models. To this aim, some knowledge of the L_{bol}–T_X evolution is needed from a (not necessarily complete) sample of distant clusters out to $z \sim 1$.

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